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Human Factors Evaluation of Night Vision Goggle Design: An Exploratory study using the Repertory Grid

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14. ABSTRACT

The main focus of night vision goggles (NVGs) research has been on developing better image intensifier tubes to achieve finer resolution, better contrast, wider field of view, larger signal to noise ratio, and advancing other tube performance related specifications. Much has been achieved in light intensification technology and NVG optics, however, if the users do not accept or prefer such modifications, they may not be able use the modified NVGs effectively. The limitation of Night Vision Goggles (NVGs), commonly used in military operations include the following: they can be cumbersome; they require training in order to achieve consistency in focusing and adjusting; some NVGs have a tendency to fog up during exertion by wearers; and their field of view is limited. Thus, there are a number of areas where improvements could be made to enhance NVG users’ acceptance and performance during night operations. Six senior non−commissioned members (NCMs) and 25 junior NCMs from the 3rd Battalion, the Princess Patricia’s Canadian Light Infantry (3PPCLI) participated in this study, which uses the Repertory Grid technique to identify, from the participants’ perspective, NVG constructs (i.e., individual’s concepts or criteria used to evaluate NVGs) that affect the overall acceptability of NVGs in dismounted infantry operations, specifically in the context of terrain traversal. The Repertory Grid technique enabled soldiers to communicate the important and relevant features of 4 different military NVGs, and identified the most salient improvements that would enhance their performance.

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Abstract

The main focus of night vision goggles (NVGs) research has been on developing better image intensifier tubes to achieve finer resolution, better contrast, wider field of view, larger signal to noise ratio, and advancing other tube performance related specifications. Much has been achieved in light intensification technology and NVG optics, however, if the users do not accept or prefer such modifications, they may not be able use the modified NVGs effectively. The limitation of Night Vision Goggles (NVGs), commonly used in military operations include the following: they can be cumbersome; they require training in order to achieve consistency in focusing and adjusting; some NVGs have a tendency to fog up during exertion by wearers; and their field of view is limited. Thus, there are a number of areas where improvements could be made to enhance NVG users' acceptance and performance during night operations.

Six senior non-commissioned members (NCMs) and 25 junior NCMs from the 3rd Battalion, the Princess Patricia's Canadian Light Infantry (3PPCLI) participated in this study, which uses the Repertory Grid technique to identify, from the participants' perspective, NVG constructs (i.e., individual's concepts or criteria used to evaluate NVGs) that affect the overall acceptability of NVGs in dismounted infantry operations, specifically in the context of terrain traversal. The Repertory Grid technique enabled soldiers to communicate the important and relevant features of 4 different military NVGs, and identified the most salient improvements that would enhance their performance.

Résumé

Les recherches sur les lunettes de vision nocturne (LVN) ont visé principalement, d'une part, le développement de tubes intensificateurs d'image améliorés afin d'obtenir une meilleure résolution, un meilleur contraste, un champ de vision plus large, un rapport signal/bruit plus élevé et, d'autre part, l'amélioration d'autres spécifications liées aux performances des tubes. D'importants progrès ont été accomplis en ce qui concerne la technologie d'intensification de la lumière et l'optique des LVN. Toutefois, si les utilisateurs n'acceptent pas ou ne privilégient pas ces modifications, ils ne pourront peut-être pas exploiter efficacement les LVN modifiées.

Les lunettes de vision nocturne (LVN), qui sont couramment utilisées dans les opérations militaires, présentent les limitations suivantes : elles peuvent être encombrantes; leur utilisation exige une formation afin d'assurer la cohérence de la mise au point et du réglage; certaines LVN ont tendance à s'embuer lorsqu'elles sont portées; le champ de vision est limité. Il y a donc un certain nombre d'aspects qui pourraient être améliorés pour faire mieux accepter les LVN par les utilisateurs et accroître leurs performances lors des opérations de nuit.

Six militaires du rang supérieurs et 25 militaires du rang subalternes du 3e Bataillon, le Princess Patricia's Canadian Light Infantry (3PPCLI), ont participé à cette étude qui fait appel à la technique de la grille-répertoire pour identifier, du point de vue du participant, les « construits » (concepts ou critères utilisés par l'individu pour évaluer les LVN) des LVN, qui influencent l'acceptabilité générale des LVN lors des opérations d'infanterie à pied, en particulier lors de la traversée de terrains. La technique de la grille-répertoire a permis aux soldats de communiquer les caractéristiques importantes et pertinentes de 4 LVN militaires différentes, et d'identifier les principales améliorations susceptibles d'en accroître les performances.

Executive summary

This study utilizes the Repertory Grid technique to elicit and determine the desirable characteristics in Night Vision Goggle (NVG) design, from the perspective of soldiers who are familiar with NVG and nighttime terrain traverse operations. This technique also developed a more meaningful understanding of NVG acceptability and serviceability (i.e., whether it is acceptable and ready to put into service). These results led to recommendations for design enhancements and concept of operation of future NVG systems, in hopes of enhancing the performance of the soldier of the future.

Six senior non-commissioned members (NCMs) and 25 junior NCMs from the 3rd Battalion, the Princess Patricia's Canadian Light Infantry (3PPCLI), Canadian Forces Base (CFB) Edmonton, volunteered in this study. Content analysis of the 83 elicited NVG constructs, were converged and mapped onto 25 core NVG construct categories. Further Cluster Analysis revealed three meaningful NVG construct clusters, namely, Functionality, Comfort and Usability. An examination of the membership of these three NVG clusters provided a better understanding of how users judged the acceptability of NVGs.

Moreover, singular value decomposition analysis of the elicited repertory grid indicated that participants valued the flexibility to convert between monocular and binocular optical configurations. It was suggested that the actual preferred configuration will depend heavily on the operational requirements. The dual configuration capability of a proposed 'hybrid' NVG was hoped to allow users to better align the type of NVG mobilized with the needs relating to context of use, hence should improve operational performance.

The Repertory Grid technique was successfully applied to allow for a better understanding of the concepts considered by participants while making meaningful discernment regarding NVG acceptability. It also successfully identified meaningful and relevant criteria to evaluate NVG; allowed for the formulation of a path model for general equipment evaluation process; indicated relative design strengths or weaknesses of the NVGs; and led to a recommended design for a dual configuration hybrid NVG for further testing and development.

Sommaire

Cette étude fait appel à la technique de la grille-répertoire afin de rechercher et de déterminer les caractéristiques des LVN qui seraient souhaitables du point de vue des soldats qui connaissent bien ces dispositifs et les opérations de traversée de terrains la nuit. Cette technique a également permis de mieux comprendre les conditions d'acceptabilité et de bon fonctionnement des LVN (c.-à-d. si les LVN sont acceptables et prêtes à mettre en service). Ces résultats ont conduit à des recommandations visant à améliorer la conception des LVN et le concept de fonctionnement des futurs systèmes LVN, dans l'espoir d'accroître les performances des soldats.

Six militaires du rang supérieurs et 25 militaires du rang subalternes du 3^{e} Bataillon, le Princess Patricia's Canadian Light Infantry (3PPCLI), Base des Forces canadiennes (BFC) d'Edmonton, se sont portés volontaires pour cette étude. Les résultats de l'analyse des contenus des 83 construits de LVN obtenus ont été regroupés et organisés en 25 grandes catégories. D'autres analyses typologiques ont révélé trois types de construits significatifs, soit la fonctionnalité, le confort et la facilité d'utilisation. Un examen de la composition de ces trois types a permis de mieux comprendre comment les utilisateurs jugeaient l'acceptabilité des LVN.

De plus, l'analyse par décomposition en valeurs singulières de la grille-répertoire obtenue indiquait que les participants valorisaient la souplesse de passage entre la configuration monoculaire et la configuration binoculaire. Il a été suggéré que la configuration privilégiée dépendra fortement des exigences opérationnelles. Un modèle de LVN « hybride » proposé, à double configuration, devrait permettre aux utilisateurs de mieux adapter le type de LVN mobilisé aux besoins liés au contexte d'utilisation, et d'améliorer ainsi les performances opérationnelles.

L'application de la technique de la grille-répertoire a permis de mieux comprendre les concepts envisagés par les participants afin de déterminer de façon pertinente l'acceptabilité des LVN. Elle a aussi permis d'identifier des critères significatifs et pertinents pour l'évaluation des LVN; de formuler un modèle de pistes causales (*path model*) pour le processus général d'évaluation de l'équipement; d'identifier les forces et les faiblesses de la conception des LVN; et de recommander une conception d'un modèle de LVN hybride à double configuration en vue d'essais et de travaux de développement.

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Introduction

Night Vision Goggles (NVGs) research and development has focused on improving NVG technology, to develop better image intensifier tubes for finer resolution, contrast, field of view, signal to noise ratio, and other tube performance related specifications. Much has been achieved in terms of the technical capabilities of NVGs, but if the users do not accept or prefer such modifications, they may not be able use the modified NVGs effectively.

The present study focuses on the human factors of NVG design. It uses the Repertory Grid technique to identify, from the users' perspective, NVG constructs (i.e., individual's concepts or criteria used to evaluate NVGs) that affect the overall acceptability of NVGs in dismounted infantry operations, specifically in the context of terrain traversal. Dismounted terrain traverse refers mainly to the dismounted movement by soldiers across various types of terrain while using NVGs.

In the present study, participants had several weeks of experience using 4 different types of NVG, while performing terrain traverse tasks across four different types of terrain, namely, dense woods, open woods, open country and urban town (in-building and urban streets). The dense forest terrain course covered a section of land where trees were close to each other with dense brush between them, making the course challenging to negotiate. The trees were spaced wider apart in the open wooded terrain and subjects could easily proceed between them. The open country terrain environment was mainly composed of tall grasses, with some tall bushes and very few trees. The urban environment comprised a series of buildings, arranged to represent a typical European town environment.

The findings of this report will assist in the development of human factors (i.e., design and performance) specifications for future NVG systems, and may help to provide guidance for manufacturing and procurement purposes.

Personal Construct Psychology and the Repertory Grid Technique

Kelly (1955) invented the Repertory Grid knowledge elicitation technique, which based its theoretical foundation on his Personal Construct Psychology. The technique provides a way of eliciting personal mental representations or core concepts (constructs or characteristics), and systematically captures the cognitive relationship among these constructs and relates them to the subject matter elements – in this case different types of NVGs. Bannister (1962) has presented a very clear explanatory paper on the theoretical foundation for the Repertory Grid technique.

The term 'personal constructs' in Kelly's theory refers to the set of bipolar mental representations or concepts which allow individuals to formulate hypotheses about things in their world, enabling them to predict outcomes and facilitate decision-making. The qualities or criteria used in making the comparisons (e.g., "weight", "fog up", etc.) are called constructs. And the things to be compared (e.g., NVG's) are called elements.

Kelly (1955) explains how anticipation may be considered as a series of mental templates (construct systems) which will be evaluated against new events or objects the person is experiencing. These templates or construct systems are an hierarchical assemblage of understanding and meaning. If there is a discrepancy between anticipated and actual experience, an adjustment will be made to the constructs of relatively subordinate (i.e., subordinate constructs) importance to increase the likelihood of fit. In turn, the newly modified template will be evaluated with the actual experience again through the process of anticipation. In this ongoing manner, the construct system will evolve and extend with each new experience. Eventually, more super-ordinate constructs will emerge with the elaborated construct systems, which will be relatively more difficult to adjust (i.e., rather stable).

The identification of super-ordinate constructs will enable one to understand how people anticipate and re-construe events or objects. By further examination of the sub-structure of people's subordinate constructs, one can identify the roles and importance of relevant physical characteristics, items and features of the events or objects.

The underlying assumption of the Repertory Grid is that the mathematical association between constructs (e.g., evaluation criteria) and elements (e.g., NVGs) reflect the psychological relationships between them as perceived by the individual (Beail, 1985; Taylor, 1990). Scheer (1996) described the Repertory Grid as a kind of test that the respondent develops him/herself, guided by the psychologist.

According to Adams-Webber (1994), the Repertory Grid technique is a reliable method of quantifying and statistically analyzing relationships between the cognitive dimensions used in performing a complex sorting task. The technique allows the detection and measurement of implicit personal constructs of a person.

In essence, the Repertory Grid helps map or model the mental processes personnel use in making comparisons between different objects (e.g., night vision goggles) or different people (e.g., air crew captains) (Hendy and Ho, 1998; Ho, 1999) or situations (e.g., aviation scenarios) (Farrell and Ho, 2000).

In a typical construct elicitation session, a participant is asked to describe how he/she distinguishes between elements of the subject matter within a specific context using a compare-and-contrast process. This process leads to the development of a matrix, i.e. the Repertory Grid itself, which shows how the participant describes the subject matter, in his/her own terms. The grid data is subjected to statistical analyses to yield a graphical representation of the structure of the participant's perceptions of the subject matter, which is used by the investigator in translating implicit data to explicit data. In this manner, the Repertory Grid program enables investigators to make precise statements as well as confident predictions about the mental models of people concerning a particular subject matter. This unique investigative technique also tends to by-pass the influence of the observer's initial frame of reference on what was observed, hence minimizing the effect of observer bias and over-reliance on subject-matter experts.

The Repertory Grid technique can be administered either by allowing soldiers to generate and explore their own evaluations (constructs) about NVG acceptability and serviceability (i.e., calibration mode), or by condensing these newly generated constructs as predefined core constructs for others to construe upon (i.e., validation mode). When utilized in the calibration mode, the Repertory Grid technique enables researchers to explore and reveal core or standard constructs on the subject matter, and when use in the validation mode, it enhances the resolution of the underlying structures among and between different elements and constructs.

Night Vision Goggles

Four types of NVGs, i.e., two binocular, one biocular, and one monocular, were used by the soldiers who participated in this study. These NVGs were selected based on their different engineering designs. All but one were type I NVGs, meaning they were of a non-see through design. The only type II, or see-through design NVG had a binocular configuration. All NVGs were attached to the subject's helmet during traverse. A brief overview of each of the four NVGs follows:

- Binocular-A (ANVIS-9), shown in Figure 1, has two independent channels that feed two separate images to each eye. Because it is a type I design, the inter-pupillary distance (IPD) is rigorously respected. This design is also one of the heaviest because of the two image intensifier tubes, and the two sets of eyepiece and objective lenses.

Figure 1: Binocular-A NVG (ANVIS-9)

- Binocular-B (AN/AVS-502), shown in Figure 2, also has two independent channels that feed two separate images to each eye. Because it is a type II (see-through) design, the objective lenses are not directly in front of the user's eyes. This design was the heaviest one because of the additional optics involved to relay the two separate image intensifier image to the combiner lenses.

Figure 2: Binocular-B NVG (AN/AVS-502)

- The Biocular NVG (AN/PVS-7D), shown at Figure 3, is a type I design that feeds the same image to both eyes utilizing a single intensifier tube. This design incorporates only one image intensifier tube, providing both an economical as well as weight advantage (through elimination of one objective lens assembly together with one image intensifier tube). However, there is still a weight penalty for having an optical train for each eye.

Figure 3: Biocular NVG (AN/PVS-7D)

- The Monocular NVG (AN/PVS-14), shown at Figure 4, is a type I design that only has one channel - one image intensifier feeding one image to one eye. This has the advantages of being lightweight, and can allow the other eye to remain dark adapted and provide peripheral vision.

Figure 4: Monocular NVG (AN/PVS-14)

Methods

Subjects

Participants were divided into two groups: the calibration group; and the validation group, which respectively consisted of 6 senior non-commissioned members (NCMs) and 25 junior NCMs. All were volunteers from the 3rd Battalion, The Princess Patricia's Canadian Light Infantry (3PPCLI) based at Canadian Forces Base (CFB) Edmonton.

Participants were familiar with and skilled in the task of nighttime terrain traverse using all 4 types of NVG, across a range of terrains, namely, dense woods, open woods, open country and urban environment.

Procedure

The participants interacted with the computerized Repgrid program (Centre for Person-Computer Studies, 1990) in their battalion's lecture rooms. The Repertory Grid elicitation process begins with a formal briefing of the detailed trial plan, the signing of a consent form. All participants in this study had dismounted terrain traverse experience using the 4 NVGs, namely, biocular (AN/PVS-7D), monocular (AN/PVS-14), binocular-A (ANVIS-9), and binocular-B (AN/AVS-502). These 4 NVGs plus an 'ideal' NVG (as perceived by the participants) are introduced as the Repertory Grid "elements" to the participant. The choice of elements (the 4 NVGs) and a dismounted terrain traverse scenario focuses the grid onto the set of possible constructs in which construing is to be investigated i.e., "to explore identifiable factors of acceptable NVGs". All participants were given ample opportunity to construe (generate distinctions concerning) all elements used in the study.

In the calibration mode, the participant is presented with three elements (types of goggle selected randomly by the computer) at a time with the question "In what important way are 2 of these elements alike and thereby different from the third? Choose the one that is different" and then "In what way does this dissimilar element differ from the other 2 which are alike?", and finally, "In what way are the 2 alike elements similar?" Following this, the participant adjusts the position of all remaining elements on the newly formed bi-polar construct scale, so as to reflect best the participant's judgement of where each element fits on the rank order scale relative to the others. This process of eliciting constructs and rating elements is repeated using another random triad of elements and continues until the participant cannot come up with further distinctions. Here, the Repertory Grid is comparable to a semi-standardized interview, where the construct elicitation procedure is standardized, but not the content (Scheer, 1996).

When used in the validation mode, participants rate each element on the scale relative to the other elements based on a set of previously elicited constructs. This approach elicits element ratings that enhance the grid's relational structure, to reveal interesting clusters or groupings of constructs, and aid in better conceptualization of the notion of NVGs acceptability.

To summarize, the Repertory Grid was administered in two experimental phases for this study:

1. The calibration phase involved using the Repertory Grid as an exploratory tool with the calibration group (i.e., 6 senior non-commissioned officers with extensive hands-on NVG experience), to elicit core NVG constructs (distinctions). Calibration group respondents made meaningful distinctions between the four NVGs and were asked to imagine the attributes of an ideal NVG. This allows for a consensus list of core NVG construct categories, commonly shared by typical users, to judge NVG acceptability.

2. The validation phase involved 25 junior NCMs using the Repertory Grid to confirm and enhance the relational patterns among the NVG construct categories identified in phase one. Furthermore, through the triad eliciting procedure similar to that used in phase one, the junior NCMs were given the opportunity to provide additional constructs or distinctions over and above the existing list of construct categories as identified in phase one.

Repertory Grid data analysis strategies

Corresponding to the two experimental phases, there were two major phases in analyzing the grid data elicited in the study: the initial content analysis of calibration phase data, and the statistical analysis of validation phase data. Statistical techniques such as Cluster Analysis and Singular Value Decomposition are used to examine the validation phase averaged grid data.

Results

Content analysis of calibration phase data

The content analysis of the calibration phase (i.e., phase one) data identifies a comprehensive list of personal NVG constructs according to the 6 senior NCMs. A total of 83 NVG constructs were elicited. Four subject matter experts (SMEs) consisting of 3 defence scientists and 1 bio-sciences officer from DRDC Toronto examined the 83 personal constructs and further classified them into 25 bipolar core categories listed in Table 1.

Table 1: 25 core NVG constructs categories

Core NVG constructs categories
1. Poor image resolution – Good image resolution
2. Poor image contrast – Good image contrast
3. Poor image field of view – Good image field of view
4. Poor depth perception – Good depth perception
5. Difficult to fit and adjust – Easy to fit and adjust
6. Difficult to focus – Easy to focus
7. Heavy fogging – No fogging
8. Heavy – Perfect weight
9. Bulky – Compact
10. Restrict mobility – Enhance mobility
11. Do not enhance speed – Enhance Speed
12. Induces eye fatigue and headache – Do not induce eye fatigue and headache
13. Not compatible with weapon – Compatible with weapon
14. Difficult to use IR illumination – Easy to use IR illumination
15. Fails to adapt to changing light levels – adapts well to changing light levels
16. Poor helmet mount design – Good helmet mount design
17. Poor NVG versatility – Good NVG versatility
18. Poor image perspective – Good image perspective
19. Poor peripheral vision – Good peripheral vision
20. Requires at least one hand to operate – Enables virtually hands free operation
21. Do not feel comfortable – Comfortable
22. Poor functionality – Good functionality
23. Difficult to use – Easy to use
24. Not durable – Durable
25. Not effective – Effective

These 25 bipolar core construct categories were use as the predetermined constructs in validation phase (i.e., phase 2) of this study.

Statistical analysis of validation phase data

In accordance with Kelly's (1955) Commonality corollary (see Ho, 1999 for a concise discussion of Kelly's corollaries), which states that it is possible for different people to have a similar construction of an event, individual grids can be summed and averaged. Grid rating data were collected from each of the 25 junior NCMs, using the predetermined construct categories resulting from the content analysis of phase one data. These ratings were summed and averaged into a 25x5 average grid matrix. The averaged grid served to consolidate a consensus representation of the shared NVG constructs that is common to all participants. Figure 5 depicts the averaged grid.

Figure 5: Averaged grid.

Display: 25coreNCM
Elements: 5, Constructs: 25, Range: 1 to 9, Context: NVG Factors affecting Dismounted Terrain Traverse

		1	2	3	4	5		
Poor Image Resolution	1	5	6	8	6	9	1	Good Image Resolution
Poor Image Contrast	2	5	7	8	6	9	2	Good Image Contrast
Poor Image Field of View	3	4	6	7	6	9	3	Good Image Field of View
Poor Depth Perception	4	4	6	7	6	9	4	Good Depth Perception
Difficult to Fit and Adjust	5	6	7	7	4	9	5	Easy to Fit and Adjust
Difficult to Focus	6	6	7	7	6	9	6	Easy to Focus
Heavy Fogging	7	3	5	7	5	9	7	No Fogging
Heavy	8	6	8	6	3	9	8	Perfect Weight
Bulky	9	5	8	6	3	9	9	Compact
Restrict Mobility	10	4	7	7	5	9	10	Enhance Mobility
Do not Enhance Speed	11	5	6	7	5	9	11	Enhance Speed
Induce Eye Fatigue and Headache	12	5	6	7	6	9	12	Do not induce Eye Fatigue and Headac
Not Compatible with Weapon	13	5	7	7	5	9	13	Compatible with Weapon
Difficult to use IR illumination	14	7	7	8	6	9	14	Easy to use IR illumination
Fail to adapt to changing light levels	15	5	6	6	6	8	15	Adapt well to changing light levels
Poor helmet Mount Design	16	6	7	6	3	9	16	Good helmet Mount Design
Poor NVG Versatility	17	5	7	7	5	9	17	Good NVG Versatility
Poor image Perspective	18	5	7	8	5	9	18	Good image Perspective
Poor Peripheral Vision	19	4	7	7	5	9	19	Good Peripheral Vision
Requires one or two hands to operate	20	5	7	7	5	9	20	Enable virtually Hands Free Operation
Do not Feel Comfortable	21	5	7	7	3	9	21	Feel Comfortable
Poor Functionality	22	5	7	7	5	9	22	Good Functionality
Difficult to use	23	6	7	7	5	9	23	Easy to use
Not durable	24	6	7	5	5	9	24	Durable
Not Effective	25	5	7	7	4	9	25	Effective
		1	2	3	4	5		

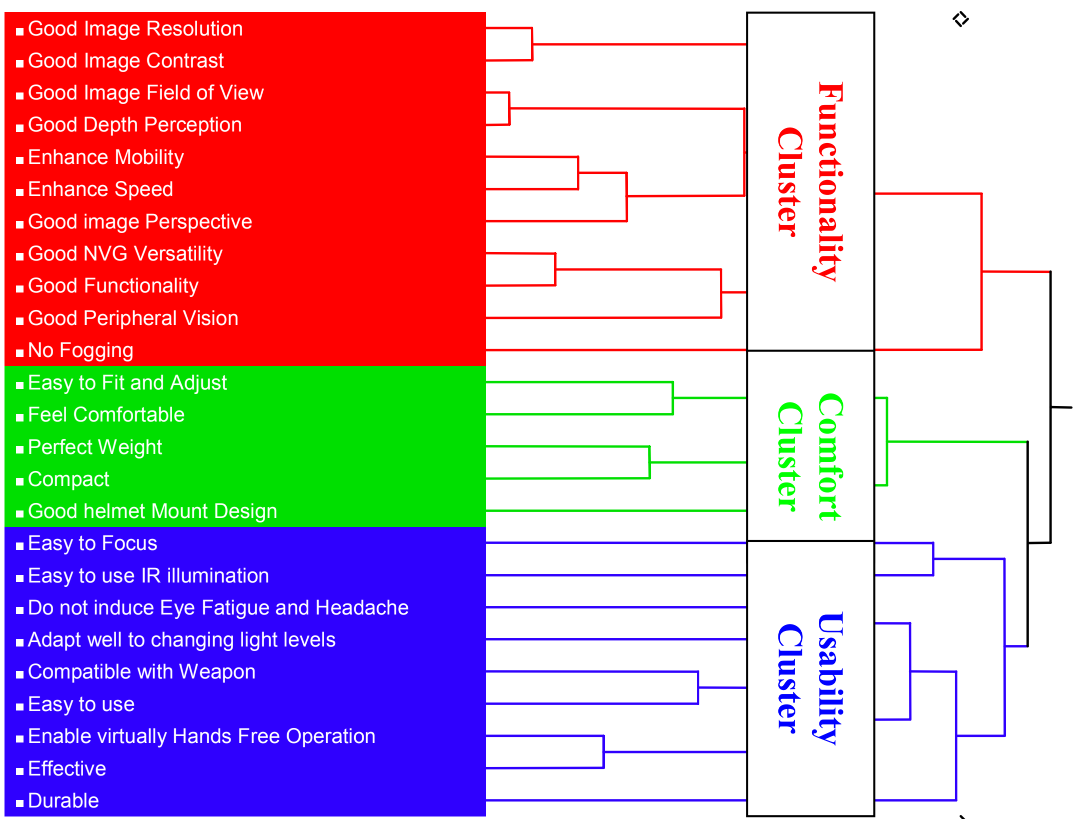
5 IDEAL
4 Binocular II (AN/PVS-502)
3 Binocular I (ANVIS-9)
2 Monocular (AN/PVS-14)
1 Biocular (AN/PVS-7D)

Cluster Analysis and Singular Value Decomposition are two different but complimentary approaches used to statistically explore grid matrices. Cluster Analysis dendrogram or tree-like diagram, and Single Value Decomposition biplot are powerful statistical graphics that can reveal relational patterns among and between NVGs (i.e., elements) and core categories (i.e., constructs).

Cluster Analysis

The outcome of the Maximum Linkage Agglomerative Cluster Analysis (Krzanwski and Marriot, 1995) applied to the averaged grid matrix, is presented as a dendrogram in Figure 6. Cluster Analysis of the averaged grid revealed three meaningful NVG construct clusters: Functionality (as depicted in red), Comfort (green) and Usability (blue). An examination of the membership constructs of these three NVG construct clusters provides a better understanding of how users judge NVG efficacy.

Figure 6: Dendrogram based on the results of the Maximum Linkage Agglomerative Cluster Analysis.



The Functionality cluster (meta-construct) pertains to different aspects affecting the visual characteristics and image quality of the NVGs (i.e., image resolution, contrast, field of view, depth perception, perspective, peripheral vision, fogging up of lenses) and their impact on the users' operational performance, such as increased NVG versatility, as well as enhanced mobility, and speed. According to the users, these vision related design, engineering and performance issues are the determinants of a functional NVG.

The Comfort cluster refers to factors affecting the users' perception of comfort while using the NVG. Factors like weight, compactness, ease of fit and adjustment, and the helmet mount designs determine how comfortable is the NVG.

The Usability cluster concerns the ease of use of various NVG functions (i.e., IR illumination, lens focus) and extended NVG capabilities (i.e., reduced eye fatigue, adaptation to sudden changes in light levels, hands free operation, and compatibility with weapons) as well as how durable is the NVG described.

The Comfort and Usability clusters are more closely related to each other than to the Functionality cluster as shown by the similarity in construct profile of the Comfort and Usability clusters to each other. A plausible explanation for this cluster pattern might be that Comfort and Usability refer to 'soft' or non-technical issues, whereas, Functionality pertains to a 'hard' or technical issue. Moreover, the overall high level of functionality in all 4 NVGs, and the ability of users to get around or adapt to discomfort (i.e., a lack of comfort) issues might also explain why user's perception of NVG acceptability seemed to be strongly related to the notion of Usability and Comfort, rather than Functionality.

Singular Value Decomposition

Singular Value Decomposition with symmetric factorization (Gabriel, 1971, 1980, 1981; Krzanwski and Marriot, 1994) of the average grid matrix identified two major underlying dimensions, which respectively account for 85.86% and 11.03% of the variance. Table 2 depicts the loadings of the 2 dimensions on each pole of the bipolar construct categories and on each NVG type. This is another method of identifying meta-constructs – in this case two principal dimensions have been identified.

Table 2: Dimension loadings based on the Singular Value Decomposition with symmetric factorization of the average grid matrix.

Description	Dimension 1 (85.86%) Loadings	Dimension 2 (11.03%) Loadings
Biocular	-2.2305	1.5673
Monocular	0.3595	1.3005
Binocular A	0.6486	-0.8840
Binocular B	-2.2883	-1.8221
Ideal NVG	3.5108	-0.1617
Good image resolution	1.8270	-1.3850
Good image quality	1.8737	-0.9135
Good image field of view	2.0326	-1.6327
Good depth perception	2.0326	-1.6327
Easy to fit and adjust	2.0943	1.2962
Easy to focus	1.4996	-0.0249
No fogging	2.5730	-2.0118
Perfect weight	2.3541	2.7487
Compact	2.6439	2.1805
Enhances mobility	2.3766	0.5007
Enhances speed	2.0401	-0.4040
Does not induce eye fatigue	1.7427	-1.0645
Compatible with weapons	2.0868	0.0675
Easy to use IR illumination	1.2940	0.2228
Adapts well to changing light levels	1.2022	-0.6854
Good helmet mount design	2.3074	2.2772
Good NVG versatility	2.0868	0.0675
Good image perspective	2.1711	-0.2530
Good peripheral vision	2.3766	-0.5007
Enables virtually hands free operation	2.0868	0.0675
Comfortable	2.6815	1.3885
Good functionality	2.0868	0.0675
Easy to use	1.7969	0.6356
Durable	1.6284	1.2766
Effective	2.3841	0.7280
Poor image resolution	-1.8270	1.3850
Poor image contrast	-1.8737	0.9135
Poor image field of view	-2.0326	1.6327
Poor depth perception	-2.0326	1.6327
Difficult to fit and adjust	-2.0943	-1.2962
Difficult to focus	-1.4996	0.0249
Heavy fogging	-2.573	2.0118
Heavy	-2.3541	-2.7487
Bulky	-2.6439	-2.1805
Restrict mobility	-2.3766	0.5007
Does not enhance speed	-2.0401	0.4040
Induces eye fatigue and headache	-1.7427	1.0645

Not compatible with weapons	-2.0868	-0.0675
Difficult to use IR illumination	-1.2940	-0.2228
Fails to adapt to changing light levels	-1.2022	0.6854
Poor helmet mount design	-2.3074	-2.2772
Poor NVG versatility	-2.0868	-0.0675
Poor image perspective	-2.1711	0.2530
Poor peripheral vision	-2.3766	0.5007
Requires at least one hand to operate	-2.0868	-0.0675
Does not feel comfortable	-1.8737	1.3850
Poor functionality	-2.6815	-1.3885
Difficult to use	-2.0868	-0.0675
Not durable	-1.7969	-0.6356
Not effective	-1.6284	-1.2766

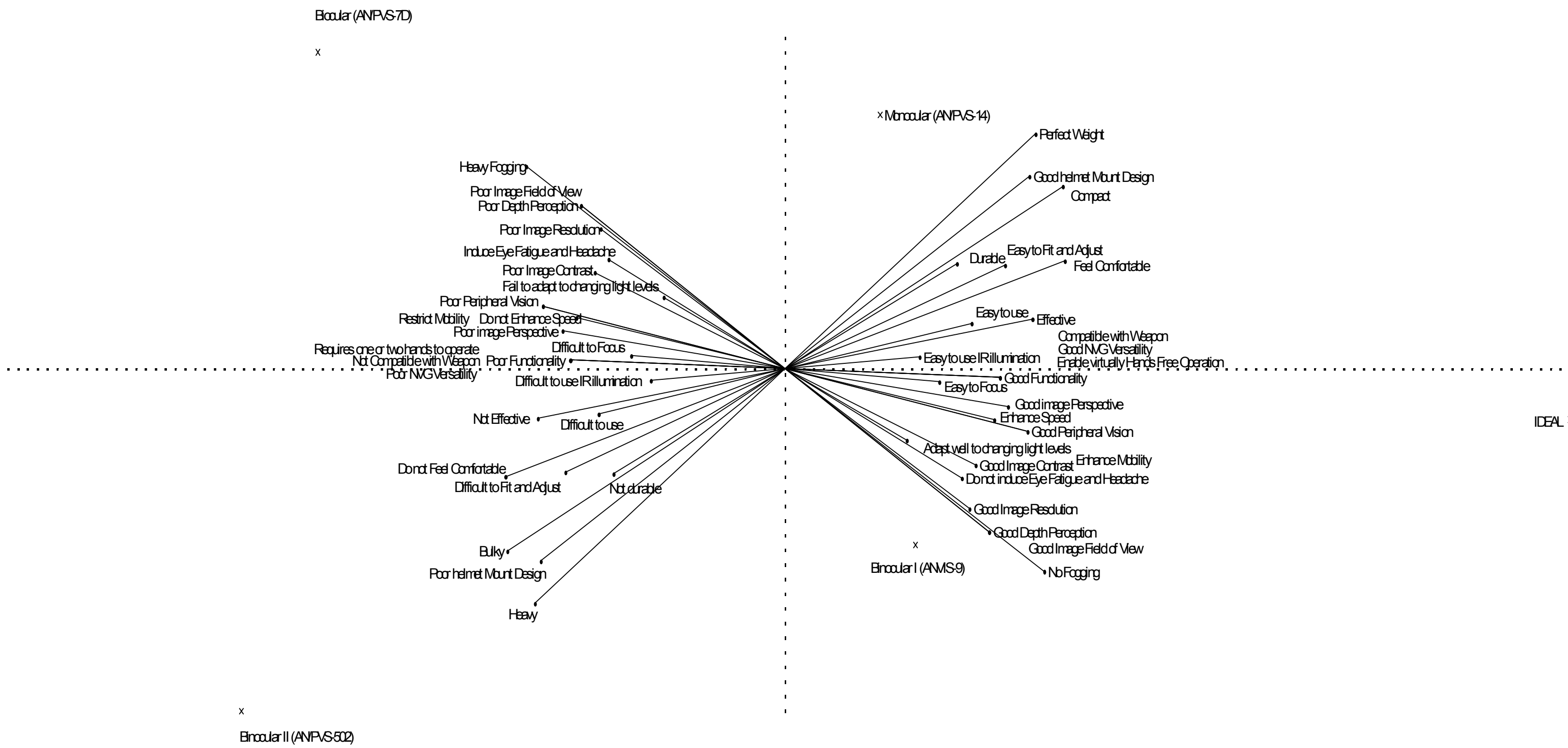
Careful examination of the loading values indicates all constructs categories seemed to fit onto one major dimension, which accounts for 85.86% of the total variance (Gabriel, 1971, 1980, 1981). Notice that the ideal NVG's Dimension 1 loading is also the largest. Thus, it is believed that the major Dimension represents non-desired versus ideal NVG characteristics. In other words, all construct categories identified in this study together define well what is desirable in an NVG and will enable a person to make meaningful and relevant distinctions between NVGs.

The secondary Dimension 2, accounts for 11.03% of the total variance, and seems to represent ocular configuration of NVG types, specifically binocular configuration versus monocular (or biocular) configuration, i.e., two input tubes versus one input tube.

These findings implied that the Monocular and Binocular A NVGs are preferred by the respondents, in different contexts, and for different reasons. Ideally, an acceptable NVG is one that has the ability to switch between monocular and binocular configuration (i.e., a kind of hybrid dual ocular NVG design that has the flexibility to convert between monocular and binocular mode of use).

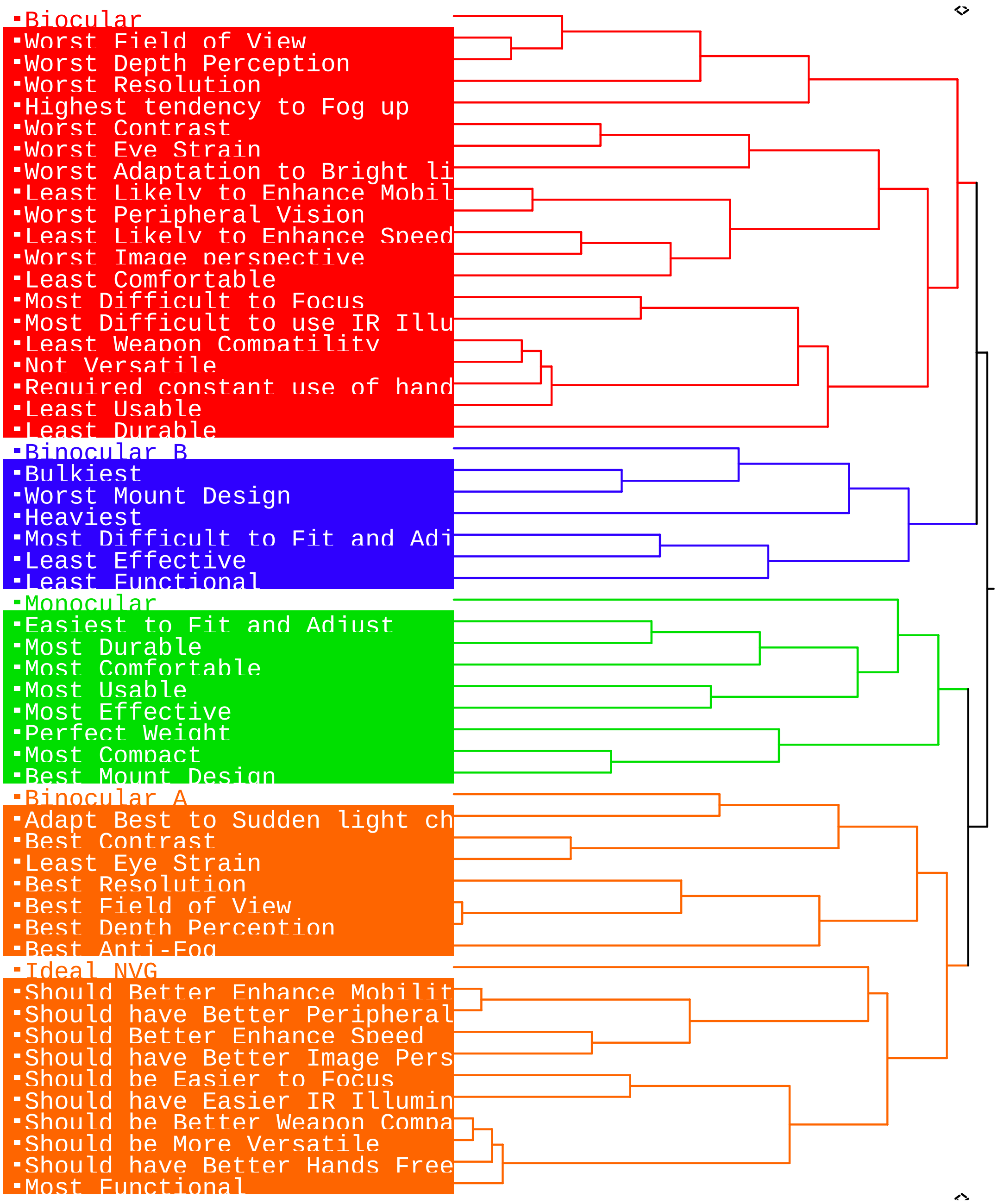
Plotting Dimensions 1 (ideal versus non-desired) and 2's (two tubes versus one tube) loadings as X and Y coordinates on a 2 dimensional plane, yields a biplot (Gabriel, 1971, 1980, 1981), as shown in Figure 7, depicting the inter-relationship or association among and between NVG types and construct categories. Their proximity with each other represents the closeness of their relationship.

Figure 7: Biplot depiction of the relationship among and between NVG types and construct categories.



A further or second order Cluster Analysis (construct grouping), of the dimensional loadings summarizes these associations into 4 distinct clusters and is presented as Figure 8. This data visualization procedure enhances the resolution of the association between NVG types and construct categories. It serves to identify the salient pole of the construct categories that correspond strongest to each NVG type. The different coloured blocks in Figure 8, aid to organize and reveal these main NVG types and construct categories clusters.

Figure 8: Cluster Analysis of the dimensional loadings summarizing the association between NVG types and bipolar constructs.



Discussions

This study, using the Repertory Grid technique, explores what criteria users based their decisions on, when asked to evaluate NVG acceptability in dismounted terrain traverse operations. The Repertory Grid technique allows for the identification of design issues that are important to NVG users. The Cluster Analysis and Singular Value Decomposition of the grid data further clarified and enhanced the relational structure among NVG types and the elicited NVG constructs. This provides a better understanding of relevant NVG design variables, operational strategies, as well as the decision-making processes involved when users evaluate equipment.

Hypothesizing a path model for equipment evaluation process

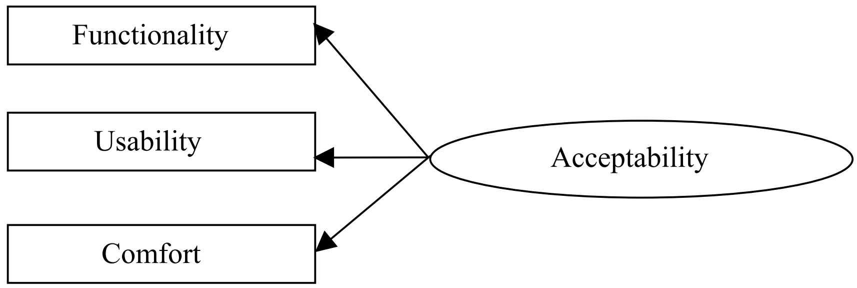
The structure of the construct dimensions can be interpreted as comprising three related conceptual groups, namely, Usability, Functionality, and Comfort, which formed the principle dimension of acceptability.

For a NVG to be accepted by users, it needs to be functional, i.e., having the capacity to accomplish its “fundamental purpose” to allow users to see in low or no light (with IR illumination) conditions. In turn, this is dependent on the quality of the image provided by the NVG intensifier tube as well as the ability of related optical systems to deliver a clear projected image to the users. Concisely, Functionality represents the ‘hard’ or technical issues of NVG design.

Coupling NVG Functionality with the capability of allowing users to see comfortably at night (i.e., the Comfort standard) as well as the capacity enabling them to benefit from the operational conveniences derived from extended NVG capabilities (i.e., the Usability standard), users will tend to conclude that the NVG is acceptable. In short, an overall acceptable NVG is one that is functional, comfortable and usable as defined by the constructs discovered in this study.

Extrapolating from these findings, a general model of how and what people based their decision on, when asked to evaluate a piece of equipment, can be hypothesized. Figure 9 depicts a diagrammatic representation of the proposed path model. The dimensions of acceptability should have considerable generality, which arises from their basis in users personal constructs, and thus will enable wide application, beyond the field of NVG evaluation. Obviously, the generalizability of this hypothesized path model needs to be further investigated and verified with data gathered from the evaluations of other equipment.

Figure 9: Proposed path model depicting the general relationship between antecedent meta-construct variables (i.e., Functionality, Usability, and Comfort) and overall Acceptability.



Granted, the exact constituent criterion for each principal evaluation standard will be equipment specific and context-of-use dependent. Nevertheless, this general path model serves to guide future evaluation processes in equipment design, development and procurement.

Relative design strength or weakness of NVGs

The second order cluster analysis of singular decomposition dimensional loadings presented in Figure 8 reveals the perceived relative strength or weakness most salient of each NVG. In relative comparison to the monocular and binocular-A NVGs, the biocular and the binocular-B NVGs are judged and perceived as being less acceptable by the users.

This finding differs from a previous study (CuQlock-Knopp, Torgerson, Sipes, Bender and Merritt, 1995), which determined that users prefer binocular goggles to the biocular and monocular goggles, and that there were no differences between the biocular and the monocular goggles. The monocular, biocular, and binocular goggles used in CuQlock-Knopp, et al.(1995) study were similar to the monocular, biocular and the binocular-A NVGs used in the present study.

The users do not prefer the biocular NVG’s one input tube-two eyepiece configuration as it tends to limit field of view, distort image perspective, hinder depth perception (because the same image from the single input tube is presented to both eyes), and restrict mobility. The rubber cups on the eyepiece also contribute to fog up the objective lenses and severely limit peripheral vision. Due to the awkward ‘between-the-eyes’ location of the tube, aiming the C7 rifle is also very difficult while using the biocular NVG. Due to these shortcomings, biocular NVG users also tend to use them only when they are really needed (i.e., either used in a hand-held as-needed mode, or necessitating the frequent donning/doffing of NVGs during operations). Hence, hands free operation becomes problematic. Overall, users found the biocular NVG, uncomfortable, least versatile, least durable and least user friendly.

The binocular-B NVG, with unconventional (type II) see-though design, was perceived to be overly heavy and bulky, and difficult to fit and adjust. The poor quality of the prototype or 'make-do' NVG helmet mount might have affected negatively on the user's perception. In order to properly and justly evaluate the binocular-B NVG, an improved dedicated mount should be developed and used instead.

On the other hand, users found the monocular NVG the easiest to fit and adjust. It also had desirable weight and compactness. Coupled with the good helmet mount design, users generally found it to be the most comfortable, durable, effective and easy to use.

Users felt that the Binocular-A NVG had the best image quality (i.e., contrast, resolution, field of view, depth perception), and had the least tendency to fog up. It was also perceived to be easy on the eyes (i.e., less eye strain), and had the best adaptation to sudden changes in light. Table 3 summarizes the list of relative design strengths or weaknesses of each NVG.

Table 3: Relative design strength or weakness most salient in each NVG.

NVG type	Salient relative strength	Salient relative weakness
Biocular		• Poorest overall image quality, i.e., the field of view, depth perception, resolution, contrast and perspective. • Severely limits peripheral vision. • Highest tendency to fog up. • Hinder speed and mobility across terrain. • Least compatible with weapon system. • Difficult to focus and use of IR illumination. • Worst eye strain and adaptation to sudden light changes. • Hands free operation problematic. • Overall, least versatile, least comfortable, least durable and least usable.

Binocular B		• Heaviest and bulkiest. • Improper prototype mount design. • Most difficult to fit and adjust (might be due to improper prototype mount). • Overall least functional and least effective.
Monocular	• Easiest to fit and adjust. • Good mount design. • Perfect weight and compactness. • Most comfortable, durable, effective and usable.	
Binocular A	• Overall, best image quality, i.e., contrast, resolution, field of view, depth perception. • Least tendency to fog up. • Least eye strain, and best adaptation to sudden change in light.	

Moreover, the analysis also further identifies areas of improvement that the users would like researchers to focus on (i.e., ideal NVG) in future NVG design and development. Table 4 summarizes the list of desired NVG improvements.

Table 4: List of desired improvement for future NVG development.

Desired NVG features, capabilities and proposed indications
• Allow for better peripheral vision and image perspective - pointing to the need for close to normal vision characteristics. • Allow for problem free, hands-free operation and easier to use IR illumination – pointing to maybe a voice activation interface. • Should be easier to focus – pointing to auto focus or focus free capability. • Future design should also focus on functional issues of NVG design so as to enhance speed, mobility, versatility and weapon system compatibility.- pointing to the need of a lighter more compact all-in-one multi-functional design, with Night Vision, Thermal Sensing, IR illumination, Normal vision capabilities.

Recommendation for a modular dual configuration NVG design – one versus twin input tubes

Users implied that they prefer the monocular and binocular-A NVGs, and ideally, an acceptable NVG for terrain traverse operations is one that has the operational characteristics of both NVG types combined. Specifically, the ideal NVG should have the ability to switch between monocular and binocular configurations (i.e., a kind of hybrid NVG design that has the flexibility to convert between monocular and binocular mode of use). The modular dual configuration capability of the proposed hybrid NVG will allow users better alignment between the type of NVG mobilized and the context of use, hence better operational performance.

Existing monocular NVGs could be assimilated in order to provide a cost efficient way to explore the feasibility of the hybrid NVG. The prototype hybrid NVG could comprise a special attachment that would join two monocular AN/PVS-14 NVGs and transform it into a functional binocular NVG. Depending on the different phases of the terrain traverse operation, different configurations and operational procedures will be preferred by the users. Therefore, it is desirable to give users the flexibility to choose between the two configurations. Figures 10a, 10b, and 10c depict the prototype hybrid NVG.

Figure 10a: Hybrid NVG – modular configuration – special attachment, and two monocular NVGs.

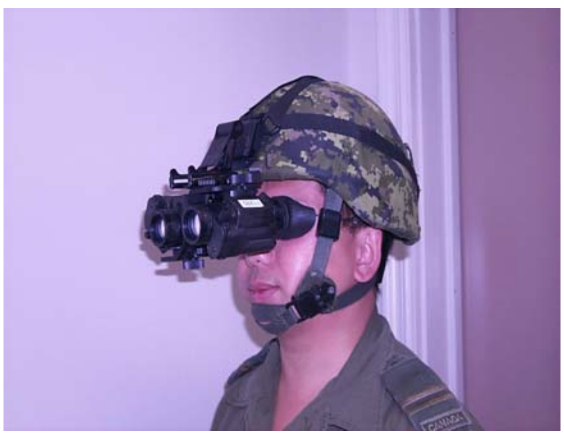
Figure 10b: Monocular mode.

Figure 10c: Binocular mode.

During operational phases, which require better image perception and less moving around, the binocular configuration should be utilized, as shown in Figure 11a. Alternatively, in situations where mobility, speed and target detection are essential, the monocular NVG on the non-dominant eye should be removed from the helmet-mounted hybrid joint attachment, and mounted onto the C7 rifle, as shown in Figure 11b. This will allow for normal vision in the non-dominant eye, which is essential for scanning immediate close-up surroundings, whereas, the dominant eye will continue to see through the monocular NVG. This latter configuration mode would avoid the visual accommodation time that is currently needed when users flip up the monocular NVG on the dominant eye and use the same eye to acquire a target through the monocular NVG mounted on the C7 rifle. It is believed that, relative to a monocular NVG and a binocular A NVG, the flexible dual configuration capability of the proposed hybrid NVG would better fulfill an extended range of military operational requirements. Further human factors trials need to be conducted to evaluate the changes in users acceptance and operational performance while using the hybrid NVG.

Figure 11a: Binocular configuration - Helmet mounted mode.

Figure 11b: Monocular configuration - Helmet and rifle mounted mode.



Conclusion

The Repertory Grid technique was successfully applied to allow for a better understanding of the concepts considered by users while making meaningful discernment regarding NVG acceptability. It also successfully identified meaningful and relevant items to be included in a NVG evaluation questionnaire, hypothesized a path model for an equipment evaluation process, indicated relative design strengths or weaknesses of the NVGs, and led to a recommended design for a dual configuration Hybrid NVG for further testing and development.

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14. ABSTRACT

(U) The main focus of night vision goggles (NVGs) research has been on developing better image intensifier tubes to achieve finer resolution, better contrast, wider field of view, larger signal to noise ratio, and advancing other tube performance related specifications. Much has been achieved in light intensification technology and NVG optics, however, if the users do not accept or prefer such modifications, they may not be able use the modified NVGs effectively.
The limitation of Night Vision Goggles (NVGs), commonly used in military operations include the following: they can be cumbersome; they require training in order to achieve consistency in focusing and adjusting; some NVGs have a tendency to fog up during exertion by wearers; and their field of view is limited. Thus, there are a number of areas where improvements could be made to enhance NVG users' acceptance and performance during night operations.

Six senior non−commissioned members (NCMs) and 25 junior NCMs from the 3rd Battalion, the Princess Patricia's Canadian Light Infantry (3PPCLI) participated in this study, which uses the Repertory Grid technique to identify, from the participants' perspective, NVG constructs (i.e., individual's concepts or criteria used to evaluate NVGs) that affect the overall acceptability of NVGs in dismounted infantry operations, specifically in the context of terrain traversal. The Repertory Grid technique enabled soldiers to communicate the important and relevant features of 4 different military NVGs, and identified the most salient improvements that would enhance their performance.

(U) Les recherches sur les lunettes de vision nocturne (LVN) ont visé principalement, d'une part, le développement de tubes intensificateurs d'image améliorés afin d'obtenir une meilleure résolution, un meilleur contraste, un champ de vision plus large, un rapport signal/bruit plus élevé et, d'autre part, l'amélioration d'autres spécifications liées aux performances des tubes. D'importants progrès ont été accomplis en ce qui concerne la technologie d'intensification de la lumière et l'optique des LVN. Toutefois, si les utilisateurs n'acceptent pas ou ne privilégient pas ces modifications, ils ne pourront peut−être pas exploiter efficacement les LVN modifiées.
Les lunettes de vision nocturne (LVN), qui sont couramment utilisées dans les opérations militaires, présentent les limitations suivantes : elles peuvent être encombrantes; leur utilisation exige une formation afin d'assurer la cohérence de la mise au point et du réglage; certaines LVN ont tendance à s'embuer lorsqu'elles sont portées; le champ de vision est limité. Il y a donc un certain nombre d'aspects qui pourraient être améliorés pour faire mieux accepter les LVN par les utilisateurs et accroître leurs performances lors des opérations de nuit.
Six militaires du rang supérieurs et 25 militaires du rang subalternes du 3e Bataillon, le Princess Patricia's Canadian Light Infantry (3PPCLI), ont participé à cette étude qui fait appel à la technique de la grille−répertoire pour identifier, du point de vue du participant, les « construits » (concepts ou critères utilisés par l'individu pour évaluer les LVN) des LVN, qui influencent l'acceptabilité générale des LVN lors des opérations d'infanterie à pied, en particulier lors de la traversée de terrains. La technique de la grille−répertoire a permis aux soldats de communiquer les caractéristiques importantes et pertinentes de 4 LVN militaires différentes, et d'identifier les principales améliorations susceptibles d'en accroître les performances.

15. KEYWORDS, DESCRIPTORS or IDENTIFIERS

(U) Night vision goggles; Repertory grid; Personal constructs psychology

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